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Original Article

Decomposition of the vertical ground reaction forces during gait on a single force plate

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Abstract

Davis and Cavanagh (1993) have proposed a solution to avoid the footstep targeting by using a large force plate but several points of Davis and Cavanagh's method remain unclear and hardly computable. **Objective:** to develop a method that decomposes left and right GRF profiles from the GRF profile recorded on a single platform. This method aims to include a systematic detection of the single to double stand-phase-instants in order to lead to accurate measurement of the vertical GRF component in typically developing children. **Methods:** Six children were asked to walk without targeting their footsteps on a set-up composed of independent force platforms. The vertical GRF component, independently measured on the different platforms, was numerically summed to obtain the corresponding global vertical GRF, to which the decomposition method was applied. Then, the validation consisted in comparing the vertical GRF computed from this decomposition to the independently measured vertical GRF. **Results:** the mean relative error between the computed vertical GRF and the corresponding measured vertical GRF of 36 double stances (6 double stances × 6 children) is equal to 3.8±2.6 %. **Conclusion:** implemented a new method to assess with known accuracy the vertical GRF component under each foot using a unique large force platform.

Keywords: Centre of Pressure, Double Stance, Ground Reaction Force Decomposition, Single Platform, Children

Introduction

In gait laboratory, ground reaction forces (GRFs) are recorded using floor-mounted force platforms in order to evaluate GRF patterns and to compute the joint torques using either the inverse dynamic approach[1-4] or the angular momentum calculus[5-7]. Traditionally, to obtain valid measurement the subject must place two consecutive steps on individual force platforms with no foot contact outside the surface of the devices (usually 50×50 cm). This condition can lead to an important number of trials before achieving valid measurements because the subjects must not voluntarily 'target' the force plate with their footsteps. In fact, in target conditions, the participant is prone to change his gait pattern which could impact GRF measurements. A change in step length, as little as 10%, has been shown to affect GRFs[8]. Thereby, targeting has been cited as a major limitation of gait studies[9].

Gait studies have intuitively attempted to reduce the effect of targeting, and simultaneously reduce the number of redundant trials, by fine-tuning each subject starting position[9] in order to make the footsteps coincide with the force platforms. Nevertheless, the number of trials made to obtain valid GRF measurements could remain important because starting position definition is especially uncertain with people with impaired gait, as well as in children, because of the spatiotemporal gait parameters variability[10]. Thereby, recording several trials across the force platforms, until a series of adequate tests have been performed, impose a lot of trials and can be very time consuming. The duration of gait evaluation is particularly problematic in children because their compliance to a research protocol is limited in time[11]. Moreover, increasing the number of trials with a participant prone to muscular fatigue can result in major methodological bias be-

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cause fatigue results in gait pattern modification[12].

For these reasons, the use of a large force plate ensures ground reaction force measurement for all trials and allows investigators to record data for numerous footsteps while avoiding the 'targeting' problem[13]. This comes with the drawback of needing to decompose the GRF for each footprint. Davis and Cavanagh (1993)[14] developed a method to decompose the left and right GRF profiles from the global values of the GRFs measured with a single large force plate. This method was based on the examination of the side-to-side oscillations of the global centre of pressure (COP) corresponding to the measured global GRF. Despite the fact that this method is the most referred one for the decomposition of superimposed vertical GRF into left and right force profiles during gait on a treadmill[15-18], several points of Davis and Cavanagh's method remain unclear and/or hard to implement. First, the method was implemented on the basis of data from a single participant walking at three different velocities. The robustness of the method has not been extensively tested and the variations between subject gait patterns have not been taken into account in the model validation process. Secondly, major assumptions are necessary in order to apply the algorithm described by Davis and Cavanagh[14]: the time samples at which the double and single support phases begin and end must be defined thanks to a visual inspection of the measured COP plot; the algorithm was based on the assumptions that the definition of the start and end of the stance phases is related to these side-to-side oscillations, which were invalidated[19]. Specifically, this point imposes to assign a threshold and define a boundary between double and single stances based on the COP path, but in numerous cases, mediolateral position of the COP does not systematically show a clear side-to-side inflection point as exposed by Davis and Cavanagh. Finally, this method could be questionable if used for children because their gait pattern differs from adults one[20] and is also known as being more variable than for adults[21], which in turn increases the variability of the side-to-side oscillations of the global COP[22-23].

In 2000, Begg[24] proposed a method to detect transitions between simple and double stance phases, but not to decompose GRF. This method for transition detection presents several major limitations: First, this one is based on observations of total GRF patterns, assuming that a local minimum is present in GRF patterns before and after each double stance phase. But as similarly mentioned here above, such assumption is practically too restrictive, since minima are not systematically present in natural GRF patterns. This assumption of a local minimum is mathematically and visually even more restrictive than the assumption of an inflection point, such as proposed by Davis and Cavanagh. Secondly, the equations in Begg's paper present neither definition nor explanation of the proposed variables, which makes it impossible to understand the calculation method. Thirdly, concerning the experimental procedure, there were only two 40 cm wide platforms in series, and not laterally shifted such as Davis and Cavanagh. It is therefore difficult to imagine that the adult participants did not perform targeted steps on the platforms. No information about step targeting is stated in this paper. Further, Begg interestingly attempted to validate the detection of transitions between single and double stance phases using pressure sensors, but also mentioned that "the two recording systems were not synchronized", which raises major concerns about the experimental procedure and the calculation accuracy. Finally, this paper only presents results on 2 healthy male participants, whose age and mass are unspecified, which is not sufficient to reasonably discuss the results.

In 2006, Kimura[25] proposed a method that attempted to get "typical" GRF and COP patterns from averaged GRFs and COPs from 5 gaits of healthy adult subjects, whose number was unspecified. The objective was not to develop and validate a method to decompose GRF during given double stance phases. Therefore this method has an unknown accuracy during specific double stance phases and is unsuitable for application to individuals performing untargeted gait.

Given that these both latest studies were non-validated preliminary works, whose objectives were not the decomposition of forces during specific double stance phases, these ones cannot serve as "golden standards" for a comparison between GRF decomposition methods applied to given participants and given double stance phases. Further, these papers highlight the fact that the development of a method for the GRF decomposition is not trivial, especially when only considering GRF pattern observations, showing the necessity to develop an innovative approach.

Consequently, based on the idea of Davis and Cavanagh, the aim of this study is to develop a new method that decomposes left and right vertical GRF profiles from the summed values measured on a single large platform. This method includes a systematic detection, i.e. practically computable, of the single to double stand phase instants and must lead to accurate result in typically developing children.

Materials and methods

Participants

Six typically developing children were included in the present study (height: 1.38 m (SD: 0.18); weight: 35.1 kg (SD: 11.1), equivalent to 344.3 N (SD: 108.9), and age: 9.3 years (SD: 2.9, range: 6-13)). Exclusion criterion was known orthopedic surgical intervention during the last 6 months. All participants provided written informed consent prior testing.

Set-up

A strain gauge platform (1.8 m long and 0.6 m wide), made of seven plates of different sizes (*Pharos System Inc.*, MA) was mounted at ground level in the middle of a walkway (10 m long). Each of the seven plates was composed by force sensors recording three-dimensional force components. Each of these plates had its own processor. These processors were triggered and synchronized. The three components of GRF were measured at the four edges of these platforms, at a sampling frequency, f_e, equal to 50 Hz[26]. The full specifications of this set-up have been detailed by Detrembleur et al[27]. The incentive behind this design was to easily record forces during untargeted gait in the walkway, enabling to obtain independent left-right GRFs without targeting steps on the force platforms, and avoiding repeating trials.

Photocells were placed at each end of the platform set-up and at the neck level of the participants. These photocells were used to assess gait regularity during the trials: the trials demonstrating a clear trend towards a velocity increase or decrease were discarded according to Tesio's criterion[28], i.e. a velocity variation superior to 40%.

Procedure

The participants were instructed to look straight ahead and to walk as naturally as possible in the walkway. Practically, all subjects walked over the force platforms wearing their clothes and shoes. No feedback information was given to the participants during the trials.

Trials were selected for analysis if the participant placed two consecutive steps on independent force platforms or sets of independent force platforms (i.e. left and right feet were not placed on the same platform), and with no foot contact outside of the device surface. Finally for each of these selected trials, the vertical components of the GRFs measured on the independent platforms, on which the participant placed their feet, were numerically summed after recording in order to obtain the corresponding global vertical GRF. Then the decomposition method was applied to the global vertical GRF. The validation consisted in comparing the vertical GRFs computed from the decomposition to the original independently measured vertical GRFs.

Six double stances performed by each of the six typically developing children were included in the data processing, giving a total of 36 double stance phases.

Theoretical investigation

During the single stances, the global GRF is affected to the corresponding foot that is in contact with the ground, and there is obviously no GRF under the other foot in aerial phase. Consequently, the decomposition of the global GRFs into left-right profiles is only necessary during the double stances. Thus, it is important to detect the exact time steps of transitions between the single and double stances. In order to detect these transitions, we have successively computed the following definitions related to the COP.

COP-related definitions

On each force platform i=1, …, n (where n=7), the local centre of pressure, LCOP, related to the system reference point O, can be determined from the i^{th} platform force data, using the following equation[29]:

$$\overrightarrow{OP}_i = (OP_{x_i}, OP_{y_i}, OP_{z_i}) = \left(-\frac{M_{y_i}}{F_{z_{i,tot}}} + X_i, \frac{M_{x_i}}{F_{z_{i,tot}}} + Y_i, Z_i \right) \quad (1)$$

where:

– the local frames of the platforms are aligned with the global frame, namely X along the anteroposterior direction and positive forward, Y along the mediolateral direction and positive to the left, Z along the vertical axis and positive upward ;

– $\overrightarrow{OP}_i$ is the vector of the LCOP position on the i^{th} platform;

– i=1, …, n is the index of the force platform;

– $F_{z_{i,tot}}$ is the total vertical GRF on the i^{th} platform;

– M_{xi} and M_{yi} are antero-posterior and lateral components, respectively, of the resulting moment on the i^{th} platform, related to the reference O;

– X_i and Y_i are the antero-posterior and lateral components, respectively, of the reference point, O_i, of the i^{th} platform, relatively to the global reference O; X_i and Y_i were manually measured for each platform;

– Z_i is the i^{th} platform height, measured from the reference O; all force platforms being fixed to the floor, Z_i is assumed to be constant and was manually measured for the set-up.

The global centre of pressure (GCOP)[30], is defined as the weighted sum of the LCOP on every contact platform. Its expression related to the system referential point O is given by:

$$\overrightarrow{OP} = \frac{\sum_{i=1}^{n} F_{z_{i,tot}} \cdot \overrightarrow{OP}_i}{\sum_{i=1}^{n} F_{z_{i,tot}}} \quad (2)$$

where:

– i=1, ..., n is the index of the force platform ;

– $F_{z_{i,tot}}$ is the vertical force data on the i^{th} platform.

By replacing the variable $\overrightarrow{OP}_i$ in Equation (2) with its formulation given by Equation (1), the GCOP can be determined as follows:

$$\overrightarrow{OP} = \frac{\sum_{i=1}^{n} F_{z_{i,tot}} \cdot \left(-\frac{M_{y_i}}{F_{z_{i,tot}}} + X_i, \frac{M_{x_i}}{F_{z_{i,tot}}} + Y_i, Z_i \right)}{F_{z_{tot}}} = \frac{\sum_{i=1}^{n} (-M_{y_i} + F_{z_{i,tot}} \cdot X_i, M_{x_i} + F_{z_{i,tot}} \cdot Y_i, F_{z_{i,tot}} \cdot Z_i)}{F_{z_{tot}}} \quad (3)$$

where $F_{z_{tot}} = \sum_{i=1}^{n} F_{z_{i,tot}}$, and $F_{zi,tot}$ have been cancelled out from the denominators in order to reduce large inaccuracies of the GCOP calculation when $F_{zi,tot}$ is low, i.e. at the beginning and the end of each footstep on a platform i. Further, Equation (3) appears as a generalization of Equation (1) for several platforms, and this is the formulation that will be considered to compute the GCOP that will be used in the following section.

On the basis of the GCOP, ΔCOP^2 is proposed as a new variable, which is defined as the squared Euclidian norm in the horizontal plane between two given time instants t and $t + T$ of the GCOP:

$$\Delta COP^2_{t,T} = (OPx_{t+T} - OPx_t)^2 + (OPy_{t+T} - OPy_t)^2 \quad (4)$$

The time evolution of ΔCOP^2 is represented in Figure 1 for the illustrative test on one subject at normal gait on the force platform set-up. This variable called ΔCOP^2 is the tool that we suggest to determine the limits between the single and double stances before decomposing the GRF profiles. More details are given in the following section.

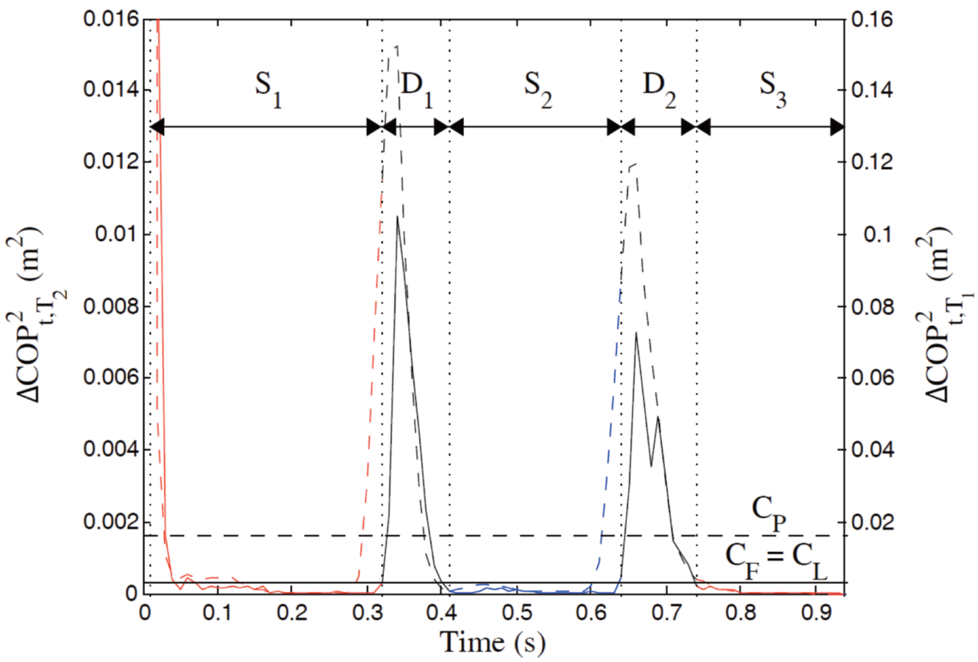

Figure 1. Time evolution of $\Delta COP^2_{t,T_2}$ (solid line; left scale) and $\Delta COP^2_{t,T_1}$ (dashed line; right scale). The vertical dotted lines represent the separations between the single stances (S_1, S_2, S_3) and double stances (D_1, D_2), detected on the basis of $\Delta COP^2_{t,T_2}$ and $\Delta COP^2_{t,T_1}$ peaks. The dashed horizontal line represents the C_P (=0.0015 m²) threshold, and the solid horizontal line represents the C_F=C_L(=0.0003 m²) threshold.

Detection of stance transitions

The method to detect each transition between single and double stances consists of three consecutive steps:

1. Detection of the ΔCOP² peak beginning in the next T_1 period, where T_1=0.1 s:
$$\Delta COP^2_{t,T_1} > C_P \quad (5)$$
2. Detection of the ΔCOP² peak beginning in the next T_2 period, where T_2=0.02 s:
$$\Delta COP^2_{t,T_2} > C_F \quad (6)$$
3. Detection of the ΔCOP² peak ending in the next T_2 period, defined here above:
$$\Delta COP^2_{t,T_2} < C_L \quad (7)$$

where C_P [m²] (P for peak), C_F [m²] (F for first instant) and C_L [m²] (L for last instant) are constant thresholds defined to distinguish the ΔCOP² peaks from the small variations of ΔCOP².

The rational for choosing the values of T_1 and T_2 periods in ΔCOP² is to have a compromise to ensure:

– a sufficient period to be sure to detect with certainty a ΔCOP² peak that corresponds to a double stance phase (as presented in Figure 1), by detecting this one early enough in the ΔCOP² data thanks to $\Delta COP^2_{t,T_1}$ and then by searching for a more accurate peak start instant using $\Delta COP^2_{t,T_2}$.

– a not too high period, by remaining on the rising edge of the ΔCOP² peak and not eventually after this one, to detect with certainty a ΔCOP² peak that indicates a double stance phase.

For robustness, these thresholds are defined as $s \cdot w^2 \cdot SF$, where:

– s is the number of samples corresponding to $\Delta COP^2_{t,T}$, which can be obtained using the definition of s=$T \cdot f_e$, where f_e is the sampling frequency; as f_e=50 Hz in our trials, then for T_1, s_1= $T_1 \cdot f_e$=0.1s·50 Hz=5 samples, and for T_2, s_2=$T_2 \cdot f_e$=0.02 s·50 Hz=1 sample.

– w [m] is the white noise magnitude measured in $\Delta COP_{t,T_2}$, approximately equal to 0.01 m in the present trials;

– SF is a Security Factor in order to distinguish a peak of $\Delta COP^2_{t,T}$ from the measurement noise during the test, which is usually considered as Gaussian white noise. According to the definition of a Gaussian distribution, a variation of three standard deviations around its mean contains about 99.7% of the noise. Thus, the choice of SF equal to 3 enables to distinguish a peak signal from the noise measurement in 99.7% of cases. In 0.3% of the remaining cases a peak will be defined instead of measurement noise. These rare cases have not been reported in ours trials.

Consequently, being given the white noise magnitude in our trials, C_P (corresponding to $\Delta COP^2_{t,T_1}$ in Equation (5)) is here equal to $s_1 \cdot w^2 \cdot SF$=5·0.01² m²·3=0.0015 m², and C_F and C_L (corresponding to $\Delta COP^2_{t,T_2}$ in Equations (6) and (7)) are here equal to $s_2 \cdot w^2 \cdot SF$=1·0.01² m²·3=0.0003 m². On the basis of the detection of stance transitions (Equations (5) to (7)) and the above thresholds values, the detected separations between the single and double stances are illustrated in Figure 1.

Decomposition of the GRFs

During each single foot stance time, the GRF under the foot in contact with the platform set-up is equal to the total force,

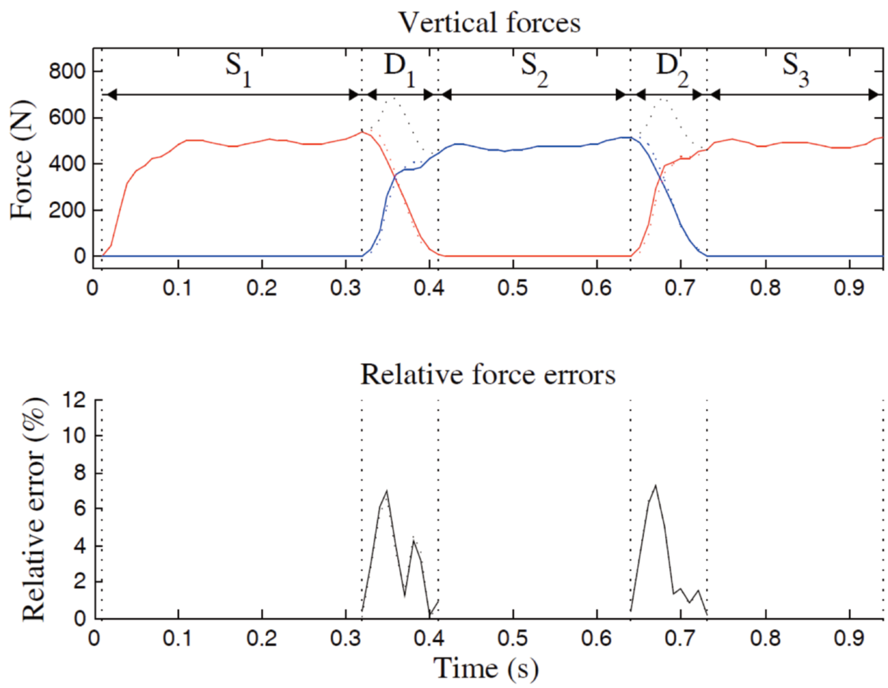

Figure 2. (Above): Time evolution of the vertical components of the GRFs approximated by splines (solid line) and the corresponding measured GRFs (dotted line); the total measured vertical GRFs are also presented in dotted lines during the double stances detected by the ΔCOP^2 peaks. (Below): corresponding time evolution of the relative vertical GRF errors between the computed and measured GRFs, for the foot losing contact (solid line) and the foot landing (dotted line).

while the GRF under the foot in aerial phase is obviously equal to zero. During each double stance period, vertical GRF component under the foot that takes off from the platform set-up is approximated by a cubic spline curve, noted $F_{z_{spline}}$. Vertical GRF component under the foot that lands on the platform set-up is approximated by $F_{z_{tot}}$-$F_{z_{spline}}$, where $F_{z_{tot}}$ is the total (summed) vertical GRF components measured on the platform set-up. Using splines has been chosen to approximate the GRF components under the foot that takes off from the platform set up, because their shapes during normal gait are generally smoother than the GRF components under the foot that lands on the platform set-up, the latter being reconstructed using the information contained in the globally measured vertical GRF.

Results

GRF error analysis

Referring to the illustrative test shown in Figure 1, the time evolution of the vertical component F_Z of the GRFs computed for each foot and the corresponding independently measured GRFs are presented in Figure 2. During the double stances, the absolute error is defined as:

$$e_{F_z} = \left\| F_{z_{computed}} - F_{z_{measured}} \right\| \quad (8)$$

where $F_{z_{measured}}$ is the measured vertical GRF and $F_{z_{computed}}$ is the computed vertical GRF during the double stance. Complementarily, we can define a relative error as follows:

$$\varepsilon_{F_z} = \frac{e_{F_z}}{\left\| F_{z_{max}} \right\|} \quad (9)$$

where this relative error balances the impact of the absolute error e_{F_z} relatively to the $F_{z_{max}}$, which is defined by the maximal total force during the double stance phase. This relative error is also presented in Figure 2 during the double stances.

In order to summarize the statistical results of the 36 double stances, Table 1 successively presents the mean, root mean square (RMS) and maximum values of the relative and absolute errors between the computed and measured vertical GRFs. The mean and RMS errors also feature the standard deviation of these errors. Finally, Table 1 also presents the linear correlation coefficients $r_{\varepsilon v}$ (resp. $r_{\varepsilon v}$) between these mean absolute (resp. relative) errors and the mean walking velocities.

Discussion and conclusion

The main result reported in Table 1 is the low mean relative error of 3.8 % between the vertical forces computed using the decomposition method, $F_{z_{computed}}$, and the corresponding measured vertical forces, $F_{z_{measured}}$, of 36 double stances of children (age: 9.3±2.9 years; weight: 35.1±11.1 kg) during untargeted gait on a unique force platform. This result represents the accuracy of the left-right vertical GRF components using this systematic decomposition method of forces, which is important to

ε_{mean}±S.D (%)	e_{mean}±S.D (N)	ε_{rms}±S.D (%)	e_{rms}±S.D (N)	ε_{max} (%)	e_{max} (N)	$r_{\varepsilon v}$	r_{ev}
3.8 ± 2.6	16.2 ± 8.4	5.7 ± 3.1	22.3 ± 10.1	24.1	68.0	-0.15	-0.02

Table 1. Statistical results of the 36 double stances: Mean ε_{mean} (resp. e_{mean}), rms εrms (resp. e_{rms}) and maximum εmax (resp. e_{max}) values of the relative (resp. absolute) errors between the computed and measured GRFs. The mean and rms errors also feature the standard deviation of these errors. Linear correlation coefficients $r_{\varepsilon v}$ (resp. r_{ev}) between these mean relative (resp. absolute) errors and the mean gait velocities are also presented.

assess before using such results to analyze the GRF patterns or to compute the joint torques using either an inverse dynamic approach1 or the angular momentum1. No gait trial was rejected, in order to check the robustness of the present systematic approach. Based on 36 double stances, the algorithm robustness can be considered as reasonable regarding the standard deviation of the relative error (2.6 %) in the decomposed forces, as given in Table 1. Finally, the linear correlation coefficients presented in Table 1, $r_{\varepsilon v}$ equal to -0.15, and r_{ev} equal to -0.02, show that the relative and absolute errors of the force decomposition are not correlated with gait velocity.

To the author's knowledge, since Davis and Cavanagh's study, no other method has been proposed to decompose the GRF measured with a single large force plate. With respect to the decomposition method proposed by Davis and Cavanagh (1993)[14] the present study adds several major innovations, concerning the systematic detection of single and double stances, the hypotheses used for the decomposition method, and the testing method. These innovations are discussed in the next paragraphs.

Firstly, in Davis and Cavanagh's method, the limits of the single and double stances are determined by the side-to-side oscillations of the global COP and global GRFs. However these limits can hardly be identified accurately because medio-lateral position of the COP does not systematically show a clear side-to-side inflection point that can be determined by either a visual inspection or a systematic detection of the COP plot. Consequently, Davis and Cavanagh's method cannot be implemented in a systematic decomposition algorithm on a device, and is further not applicable for any gait pattern, even with a visual inspection. Finally, the assumption of the side-to-side inflection point is particularly questionable in children gait analysis because of the GRF pattern variability[21] and the resulting COP variability. In the method presented here, the limits of the single and double stances are determined by the peaks of a variable called ΔCOP^2 that is very sensitive to subject COP displacement during gait (e.g. in Figure 1). Moreover, the condition applied on ΔCOP^2 in Equations (5) to (7) can be easily computed, and result in a systematic determination of the stance phases in typically developing children.

Secondly, the problem of force decomposition on a single platform consists in a system of two equations, the one describing the equilibrium of forces in the vertical direction, and the other one describing the equilibrium of moments about an anteroposterior axis of the force plate. A first key difference compared to Davis and Cavanagh's paper has been the measurement of these antero-posterior and medio-lateral forces and their using in the equilibrium equations. Further, these equations include four unknowns, both left and right vertical forces and both left and right positions of the COP on the lateral axis, leading to a problem of uncertainty. So a second key difference compared to Davis and Cavanagh's paper is the way in which this uncertainty is solved. After having supposed that a clear side-to-side inflection point can be detected, Davis and Cavanagh's method arbitrarily fixes the medio-lateral COP coordinates of the foot that takes off from the platform set-up during the double stance to threshold constants, called W_{L2} and W_{R2}, representing the minimum and maximum excursions of the measured COP. This method leads, as visually estimated on the figure of COP locations in Davis and Cavanagh's paper, to an absolute error of around 3 cm on the COP of the foot that takes off. This error has a clear impact on the accuracy of the decomposed GRFs, following the COP-GRF relation reminded by Equation (1). In the present study, the vertical GRF under the foot that takes off from the platform set-up during the double stance is approximated by cubic spline curves, $F_{z_{spline}}$, between its last value, equal to $F_{z_{tot}}$, at the transition from the single to the double stance, and its final value of zero, at the end of this double stance. During this double stance, the total vertical GRF of both feet, measured by $F_{z_{tot}}$, is respected because the GRF components under the foot that lands on the platform set-up are approximated by $F_{z_{tot}}$- $F_{z_{spline}}$, so that the sum of GRFs under the left and right feet is always equal to the measured global GRF. The rational for usage of a cubic spline interpolation to approximate the GRF components under the foot that takes off from the platform set up was justified by the fact that cubic spline curves are made to interpolate smooth transitions, enabling to take into account the fact that GRF shapes under the foot that takes off are smoother than GRF shapes under the foot that lands on the platform set-up, which show variable impacts at each step due to heel strike. Further, amongst interpolation techniques, cubic spline interpolation is generally preferred over polynomial interpolations because the interpolation error are smaller than low degree polynomial splines, and spline interpolation avoids the problem of Runge's phenomenon, i.e. oscillation at the edges of an interval, which occurs with high degree polynomials[31]. Concretely, this cubic spline was implemented using the «spline» function from MATLAB, which consists in a classic cubic spline data interpolation process[32].

Thirdly, our method was tested on 36 double stances (6 double stances×6 children) during untargeted gait. For these trials, the validation consisted in systematically comparing the vertical forces computed using the decomposition method, $F_{z_{computed}}$, and the corresponding actually measured vertical forces, $F_{z_{measured}}$. Davis and Cavanagh's method was only tested on one male adult subject (age: 32 years; weight: 700 N, i.e. around twice the mean value of the children weight here: 344.3 N), performing only two times three gait trials at different velocities. Further, the results of force decomposition were not presented considering the whole double stance, which does note enable one to assess the mean or maximal errors of the decomposed forces, and consequently does not enable one to appreciate the quality of Davis and Cavanagh's method. Finally, Davis and Cavanagh do not indicate if the subject performed untargeted gait on both Kistler force plates they used (model: 9287; length/width: 0.42 m).

Further, let us note that this paper focuses on the vertical component of ground reaction force (vGRF) because it represents the major component of the ground reaction force during gait, and the vertical ground reaction force is a useful information to characterize kinetic gait pattern[33]. These vGRF are commonly used as biomechanical indicators in gait evaluation, particularly in diabetic neuropathy[34,35], chronic stroke[36], scoliosis[37], or following hip arthoplasty[38]. Besides gait evaluation, vGRF are commonly used in analyzes of running[39], jumping[40,41], sit-to-stand[42] and standing balance[43]. Moreover several walkway systems only measure the vertical component of the ground reaction force with large force plate[13].

As a limitation of the study, the algorithm of detection of stance transitions depends on threshold values, which depend on the white noise magnitude, *w*. This one consists in the static white noise of the measurement system only. Additional noise components introduced by the subject movement, such as the resonance of the platforms after a hard landing of a foot or after the lift off of a foot, or the force offset drifts during measurement, could be accounted for by increasing *SF*. The robustness has only been calculated considering a subset of possible practical measurement side-effects/errors and only considering healthy children. It is therefore unclear how well the algorithm can be used with non-typical movement patterns. Further studies will be needed to validate the proposed method in other populations including people with gait impairment.

In conclusion, this paper presents the first method enabling the decomposition, in a systematic and robust way, of the left-right vertical GRFs on a single platform during untargeted gait. Applied to 36 doubles stances of children, this method gives a good relative mean error of GRF (3.8 %) and a reasonable variability (2.6 %), considering that GRF during gait is more variable in children than in adults[21]. Nevertheless further studies are needed to validate this method in other populations including persons with gait impairment.

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